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The Crushed Stone Journal

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THE CRUSHED STONE JOURNAL

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Concrete for Pavements[1]

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• **Concrete for highways should have high durability and high flexural strength. The various forces which influence pavement concrete are discussed in the present article to show why these two necessary properties are so vital to the life of the pavement.**

IT IS the purpose of this presentation to discuss the qualities which are desirable in concrete for use in pavements and, finally, to describe a method for proportioning pavement concrete. To properly encompass the subject of "Concrete for Pavements", it becomes necessary to give thought, not only to the hardened concrete and the various forces which attack it as it exists in the pavement, but it is equally important to consider concrete in its plastic state, for the important phenomena which influence its future behavior begin to act immediately after the concrete is deposited on the subgrade.

Accordingly, it is appropriate to begin the study of pavement concrete while it is still unhardened and immediately after it is placed. It will be assumed for the present that the concrete is made with standard portland cement with no air entraining agent added to it or to the concrete. Almost invariably the first thing that occurs in this newly placed concrete is a form of sedimentation. Concrete having sufficient plasticity to be placed and finished always has more water in the mixture than is necessary to hydrate the cement, and since the water has a specific gravity of only 1 in comparison with a specific gravity of roughly 2.65 for the aggregates and 3.15 for the cement, some of the water tends to rise up to the surface as the heavier materials settle. This phenomenon is evidenced by the water which is readily visible on the surface a short time after it is finished and which may at times even run over the side forms in the form of clear water.

Quite evidently, due to water segregation, or water gain, there must be a general decrease in the ratio of water to cement in the mixture below the surface and a very decided gain in water-cement ratio in the top layers of the concrete. A weak and porous surface layer is thereby created exactly in the position where it should not exist and the surface of the concrete is thereby rendered vulnerable to attacks by freezing and by the calcium and sodium salt solutions so generally used for ice removal. Thus, within a matter of minutes after the concrete has been deposited the phenomenon of sedimentation and resulting water gain at the surface has created a weak surface layer which is extremely undesirable in pavement concrete or in any concrete subjected to the weather. Water gain is one of the important phenomena which should be given very careful consideration in connection with the design of any pavement concrete.

[1] Presented before the Harvard Graduate School of Engineering, Harvard University, Cambridge, Mass., August 29, 1946.

Some cements retain the mixing water in place better than others and sands with sufficient fine material passing through the No. 50 sieve (preferably at least 10 percent) are also helpful in retaining the mixing water in the body of the concrete and, of course, air-entrainment is now recognized as immensely beneficial in preventing water-gain.

Years ago this harmful phenomenon of water-gain was recognized by the engineering profession and its harmful effects were overcome by a system of delayed finishing which was very effective. It consisted of trowelling the surface with long handled lutes for an hour or more after the initial striking off, and to dry up the excess water which rose to the surface, a mixture of dry cement and sand was sprinkled and troweled into the surface. This finishing had two effects. It tended to compact and densify the surface of the concrete and it produced a mortar surface having a low water-cement ratio because of the added dry materials. There is no question that this method of finishing produced a surface which was durable when exposed to the weather. However, it was patented and no doubt involved high labor costs, because of hand methods used. Probably, also, it produced a rough riding surface as measured by present day standards.

The results obtained, however, illustrate a principle, namely, that high durability can be obtained by the production of a dense mixture having a low water-cement ratio. This same beneficial effect of high density has been noted by investigators of the durability of concrete pavements, for they mention the fact that footprints in pavement surfaces persist long after the rest of the surface has become displaced by scaling and frequently, also, the edges of the pavement formed by the edging tools remain long after the rest of the surface has been destroyed. These are both cases of compaction of the surface by delayed finishing. Quite evidently, it is not enough to merely design and produce satisfactory concrete, it must be further protected by proper treatment.

At this stage of unhardened, but finished concrete pavement, the subgrade may exert a deleterious action. Some subgrade materials swell when acted upon by water and if balls of soil having high swelling characteristics exist in the subgrade, they may take up water from the concrete and in swelling will produce slight knobs in the finished surface. Under these conditions a granular subgrade treatment would be beneficial. Some subgrades such as the loess or wind-blown, finely granular soils, for example those found in the middle west, are highly absorbent and have been known to cause excessive initial cracking of the concrete. The cure for this condition is to use a waterproof treatment of building paper on the subgrade to prevent the rapid extraction of the mixing water from the newly deposited concrete. Mere sprinkling of the subgrade under these conditions seems to be insufficient.

Initial Temperature Cracking

The concrete is now in place on the subgrade and has been finished to the proper surface; the phenomenon of water-gain has taken place with its previously described bad effects and the concrete begins to set. By the following morning it has attained some strength, but it is still very weak and particularly so in its resistance to tension.[1] This very weakness at this period makes it vulnerable to the production of insipient transverse cracks which may not be immediately visible, but which may show up at a later period. These cracks are due to a decrease in temperature which almost invariably takes place at night and they may not occur unless the fall in temperature is of sufficient magnitude. The decrease in temperature itself has no effect, except as it tends to shorten the length of the concrete slab. If the slab were laid on ball bearings and were provided with expansion joints, there would be no transverse cracking because there would be no forces to resist the contraction which takes place due to a fall in temperature. The fact is, however, that a very considerable amount of friction is developed between the subgrade and the underside of the slab and as contraction of the slab proceeds, forces of friction develop which produce tension in the concrete, sometimes in excess of the tensile resistance. When that happens a crack occurs.

Subgrade Friction

It will be interesting to look into this matter of friction a little further. Many years ago tests were made by the Bureau of Public Roads to determine the amount of subgrade friction developed when a concrete slab is drawn over the subgrade. A slab two feet wide and six feet long and six inches thick was used in these tests and each slab was placed on a different type of subgrade. Force was applied at the end of the slab and its movement under a gradually increasing force was measured by means of an Ames dial.

The results of the tests [2] are shown in Fig. 1. In one series the subgrade was firm and damp, in the other series the subgrade was extremely wet and soft. Note that when the subgrade was firm, the

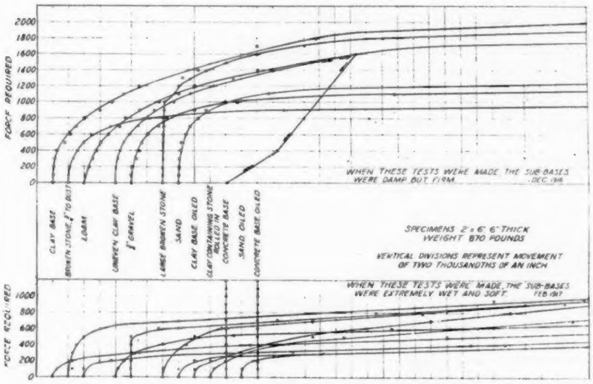

Photo by Courtesy Public Roads Administration

FIGURE 1. FRICTION TESTS OF CONCRETE ON VARIOUS SUB-BASES.

coefficient of friction varied with the amount of movement of the slab and extended up to a value of 2000/870 = 2.3. When the subgrade was wet, the maximum coefficient of friction was in the vicinity of 1000/870 = 1.15. The kind of subgrade made a difference in the coefficient of friction. When the subgrade was firm, apparently broken stone base composed of ¾ in. crusher run stone gave the least value, whereas when the subgrade was wet an oiled sand subgrade gave the low value. More recently,[3] Public Roads Administration made another series of tests given in Table I, using slabs of different thickness.

TABLE I.—COEFFICIENTS OF SUBGRADE RESISTANCE FOR CONCRETE SLABS OF DIFFERENT THICKNESSES ON A SILT LOAM SOIL (CLASS A-4) *

Slab Thickness (in.)	Coefficients of resistance for displacements of— 0.01 in.	0.02 in.	0.03 in.	0.04 in.	0.07 in.	0.10 in.†
8	0.8	1.2	1.5	1.8	2.1	2.2
6	0.9	1.3	1.6	2.0	2.4	2.5
4	1.1	1.5	1.8	2.2	2.8	3.1
2	1.3	1.7	2.1	2.5	3.3	3.5

* Data from table 3, Public Roads, November 1935.
† Displacement of 0.10 inch corresponds to maximum horizontal resisting force that could be developed.

The results of these two tests made at different times, in general, are in agreement. Apparently the resistance offered by the subgrade is composed of two elements; first, "a resistance caused by an elastic or semi-elastic deformation within the soil and, second, a resistance which approximates closely that of simple sliding friction." It is quite apparent that at times the frictional resistance may extend up to a value equal to twice the weight of the slab when a large movement takes place and it extends down to nearly zero when the slab moves very little. Thus, in a long slab the greatest frictional resistance would be at the ends of the slab and the least would be at the center where practically no movement takes place.

The tensile stress created in the slab may be roughly calculated by equating the total force of friction existing from the free end up to the section in question to the total tension produced in the slab and this may be written in the form of an equation as follows:

$$w \times l \times f = a \times S$$

where—

w = weight of concrete per foot of length when 12 inches wide
l = the length in feet between the free end and the section in question
f = coefficient of friction
a = area of cross-section of slab 12 inches wide
S = unit stress in tension

The above equation could be written in more exact form by taking into account the variation in friction between the free end and the center of the slab, but it is exact enough for illustrative purposes.

It is true that in general the tension thus produced is not very large, perhaps 50 or 60 psi, but it is equally true that the tensile resistance developed immediately after the concrete has hardened is very small and thus the tensile resistance may be exceeded by the tensile stress produced. When this happens a crack is formed.

Probably this early temperature stress is not important except when a very sudden and violent drop in temperature takes place at night, just after the concrete has been placed on the subgrade.

Moisture Changes and Their Effect on Expansion and Contraction

The slab has now hardened and, as is common practice, it is subjected to some kind of curing operation which acts, depending upon the nature of the curing, to either retain as much of the original mixing water in the concrete as possible or to supply additional water. The use of membrane curing methods is typical of the first type of curing and the use of cotton mats, wet earth or ponding are examples of the second type. Keeping the concrete wet is important for two principal reasons. First an ample supply of water is needed to make for con-

tinuous hydration of the cement, for without this continuous hydration there would be very little gain in strength. Second, the moisture condition of the concrete has a very important effect on the volume changes in concrete. If concrete is kept wet, it shows a slight expansion and when it is allowed to dry out, it begins to shrink.

Many investigators have determined the expansion and contraction which take place in concrete as the result of moisture changes and typical of such investigations are the results shown in Fig. 2. These

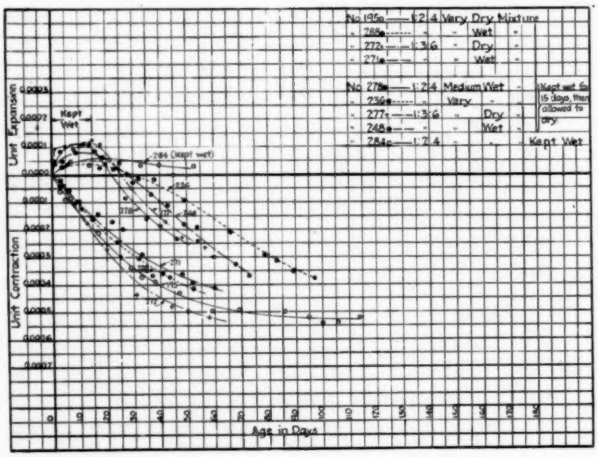

Photo by Courtesy Public Roads Administration

FIGURE 2. EXPANSION AND CONTRACTION OF CONCRETE WHILE HARDENING.

tests were made by the speaker many years ago [4] and show an expansion of roughly 0.0001 in. per inch of length due to initial wetting and a contraction in the neighborhood of 0.0004 to 0.0005 in. per inch of length due to drying out. Neat cement may contract in the neighborhood of 0.002 in. per inch, or five times as much as concrete. In fact, the moisture shrinkage of concrete is due largely to that of the cement.

As long as the concrete is kept expanded by keeping it sufficiently wet, it is subjected to a slight compressive stress, but if it is allowed to dry out shrinkage will take place and, obviously, if shrinkage ensues while the concrete is still weak, tensile stresses will be developed due to the friction in the subgrade. The high importance of sufficient curing to prevent contraction in the early stages of hardening becomes very obvious. The slight initial expansion due to moisture is beneficial since it maintains the concrete in a slightly compressed condition.

Differential Moisture Effects

There is still another moisture effect which should at least be mentioned, namely, the fact that a concrete road slab, since it is subjected to capillary moisture action from the subgrade and to evaporation from the surface of the slab during times of dry weather and to free moisture in times of wet weather is very apt to have a variation in percentage of absorbed moisture from the top to the bottom. Obviously, if the bottom is exceedingly wet and the top of the slab is very dry, there would be a tendency for the bottom of the slab to expand in length and for the top of the slab to shrink. The result would be some curling or warping of the slab, thus producing a slightly concave upper surface and a convex lower surface. Investigations of the importance of this phenomenon are extremely difficult to make and data to evaluate the stresses thereby produced are practically non-existent. Probably, however, this warping effect due to differential moisture conditions between the top and the bottom of the slab is not very great, largely because absorption takes place with great rapidity in concrete and, consequently, the difference in moisture content between the top and bottom of the slab probably is not sufficiently large to make for critical differences in volume changes in the concrete. Nonetheless the possibility of stresses due to moisture warping does exist. Such stresses definitely would exist if proper curing methods were not used.

Temperature Effects

Concrete, like practically every other solid material, suffers a change in volume when subjected to changes in temperature and, in order to properly inquire into the effects of temperature changes, it is important to know something of the coefficient of expansion of concrete, particularly as it may be affected by the concrete constituents. The coefficient of thermal expansion of concrete including neat cement and mortar [5] extends from a minimum of approximately 0.000004 to a maximum of 0.000009 per degree F. An average value for thermal coefficient of expansion might be taken at 0.000005 per degree F.

Apparently, the coarse aggregate plays the biggest part in influencing the thermal coefficient of expansion and there is a big difference in the thermal coefficient of expansion of aggregates from different sources. Measurements have been taken on the expansion properties of rocks by Iowa State College and reported in Bulletin 128 by John H. Griffith and

entitled, "Thermal Expansion of Typical American Rocks".[6]

Rocks having the highest coefficients of expansion are the siliceous aggregates, chert, sandstone and quartz, with a coefficient of expansion of about .000007 per degree F. The limestones as a class have the lowest thermal coefficient of expansion and in general range from .000003 to .000004 although there are exceptions. The trap rocks, in general, have a low thermal coefficient of expansion approaching that of the limestones. It is not safe, however, to assume any definite thermal coefficient of expansion for any rock merely because it is of a given type, for there are too many exceptions to any average thermal coefficient which may be assigned to that type.

The thermal coefficient of expansion of concrete, although affected by that of the coarse aggregate does not have as great a range in expansion as the aggregates themselves. However, there is enough range in thermal coefficient of expansion of concretes depending upon the aggregates to make this value have significance because, as will be pointed out later, there can be a significant difference in thermal stresses in concrete pavement due to differences in thermal coefficient of expansion of the concrete.

Just as in the case of moisture changes, changes in temperature affect the stresses in concrete pavement slabs in two different ways. As the temperature of the slab decreases throughout its depth, the slab contracts and slides over the subgrade. This motion is resisted by the forces of friction between the slab and the subgrade material and more or less direct tension is developed which, although possibly not great enough alone to cause cracking, except in the initial stages of setting, still, it may add to the tension produced by other causes and thus may be a contributor to the failure of the slab.

It will be interesting to make some rough calculations of the probable tension produced in the center of a slab 60 ft. long when the temperature falls 50° F., from 70° down to 20° F. The two ends of the slab will move toward the center by an amount equal to .000005 x 50° x 30 ft. x 12 in. or .09 in., or roughly 1/10 of an inch. Assuming that the average coefficient of friction between the end of the slab and the middle of the slab is 1.0, the total force of friction developed over the length of half the slab, namely, 30 ft., would be, for an 8 in. thickness of slab, 30 x 8/12 x 150 = 3000 lb. This total force will be resisted by an area of concrete equal to 8 x 12 = 96 sq. in. and, accordingly, the unit tension produced would be 3000/96 = about 31 psi.

If the average coefficient of friction were doubled this stress would likewise be doubled. Thus, it is seen that the direct tension produced in concrete due to a fall in temperature, such as might be expected under extreme conditions, is rather small and of itself is not of sufficient magnitude to cause the slab to crack. Only when combined with other stresses does this direct tensile stress have any significance.

The longer the length of slab the greater will be the direct tension produced by a change in length of the concrete and of course it is conceivable that even after the concrete has hardened and has attained its full strength, there can still be enough direct tension produced by contraction of the concrete to crack it transversely.

It is quite evident, however, that one must look elsewhere for the frequent transverse cracks which are seen in many concrete road slabs.

Warping Stresses Due to Temperature Differentials

There is a more important stress creating effect due to changes in temperature than the direct stress produced as just described and that is the warping effect caused by differences in temperature between the top and the bottom of the slab. During the day when the top of the slab is subjected to the intense heat of the sun, the top surface will become considerably warmer than the underside of the slab, for the concrete will convey the heat to the underside very slowly. At night, the top of the slab will be cooled and it will lose heat more rapidly than will the bottom of the slab and, consequently, at night the top of the slab may become cooler than the bottom. Bradbury suggests the following maximum temperature differentials per degree Fahrenheit per inch of slab thickness.[7]

	Day	*Night*
Spring and Summer	+3.0°	—1.0°
Fall and Winter	+2.0°	—1.0°

Plus sign indicates top surface of slab warmer than bottom; minus sign, top cooler than bottom.

In the spring and summer, in a slab 8 inches in thickness, the top may be expected to be 8 x 3° or 24° hotter than the bottom, while at night the top of the slab may be expected to be 8° cooler than the bottom. During the day, therefore, since the top is expanded by heat more than the bottom, this slab will assume a shape which is convex upward. It bends, not only transversely, but longitudinally, and the corners are forced into hard contact with the sub-

grade, whereas the center of the slab may actually leave the subgrade.

At night the reverse is true. Then the slab becomes concave upward and the corners of the slab are bent upward, actually out of contact with the subgrade. These are facts which have been confirmed by numerous deflection measurements taken on concrete road slabs to determine the extent of the vertical movement which may take place due to temperature differentials between the top and the bottom of the slab. It can be readily understood that if the slab is warped either up or down, and therefore no longer has uniform bearing on the subgrade, it will be subjected to bending moment due to the dead weight of the slab alone.

The simplest conception of the stress due to temperature differential is that in which the top is cooler than the bottom and the slab has been bent upward in a longitudinal direction out of contact with the subgrade.

Let it be assumed that the slab is 40 ft. long, that it is 8 in. thick and that it rests on solid rock so that when it is warped it bears only at the center. The bending moment at the center due to the overhanging length of 20 ft. and considering a width of 1 foot, would be 20 ft. x 8/12 x 150 lb. x. 10 ft. x 12 in. and the resisting moment is—

$$S \times 12 \times \frac{h^2}{6}. \text{ Consequently, } S = 1880 \text{ psi}$$

and since the modulus of rupture of suitable pavement concrete is not far from 800 psi, it is quite apparent that under the above conditions a transverse crack would form in the center of the 40 ft. slab.

Let that slab be reduced to 20 feet in length and the stress now becomes a quarter of that amount or 470 psi,—still a very high stress but not sufficient alone to cause a transverse crack due to temperature. However, when combined with traffic stresses, excessively high longitudinal bending stress would be produced as a combined traffic and longitudinal temperature stress. Even in a slab 20 ft. long, under the conditions named, there would result a high temperature stress.

Most subgrades fortunately do not have the rigidity of rock. Consequently, when warping takes place due to temperature changes, instead of there being a line of contact, or a point of contact, at the center of the slab, there is a surface of contact and the subgrade is deformed and indented as the slab rests upon it. Therefore the overhang is not as great under actual conditions as under the assumed condition of a hard rock support. To some extent this alleviates the temperature stresses produced by a differential in temperature between the top and the bottom of the slab. Even on a hard subgrade the warping stresses are less than indicated because the deflection of the slab under its own weight reduces the length of overhang assumed possible in the preceding examples. If the weight of the slab is sufficient to prevent it from warping away from the subgrade except near the ends, the maximum warping stress S in the slab will approximate—

$$\tfrac{1}{2}teE, \text{ where}$$

t = temperature differential between top and bottom of slab.

e = thermal coefficient of expansion.

E = modulus of elasticity of the concrete.

Thus, if t = 30°, e = .0000038 and E = 5,000,000

$$S = \tfrac{1}{2} \times 30 \times 0.0000038 \times 5{,}000{,}000 = 285 \text{ psi}$$

If the concrete has a high coefficient of expansion, (e = 0.0000066), then

$$S = \tfrac{1}{2} \times 30 \times 0.0000066 \times 5{,}000{,}000 = 495 \text{ psi}$$

The significant effect of thermal coefficient of expansion of concrete on warping stress is clearly shown by the preceding example. High warping stress may result in one concrete and relatively low warping stress in another, due to their respective thermal coefficients of expansion.

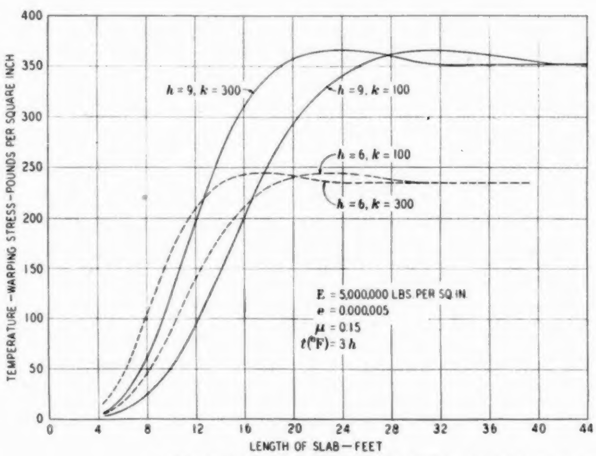

Photo by Courtesy Public Roads Administration

FIGURE 3. TEMPERATURE WARPING STRESSES—EDGE OF SLAB.

In Fig. 3, taken from a paper by E. F. Kelley in the June 1939 Journal of the A. C. I. are shown curves which illustrate the effect of the subgrade in relieving longitudinal temperature stresses. The value k is Westergaard's "Modulus of Subgrade Reaction". For the present it is sufficient to say that a value of

$k = 300$ indicates a harder subgrade than a value of 100. Note that when $k = 300$ and the slab thickness $h = 9$ in., the maximum warping stress occurs when the slab is 24 feet long while when $k = 100$, the subgrade is softer and the slab can be 32 feet long for the same warping stress to exist.

The transverse temperature stresses due to differential temperatures would be roughly calculated in much the same way as just described. This method is not exact and perhaps would offend the sense of accuracy of those who take into account the fact that the slab is warped in all directions, with the consequent influence of warping in one direction on the stress produced in a direction at right angles to this. It is not the purpose of this paper to discuss in detail the more exact methods for calculating temperature stresses, but merely to show, in a general way, why they exist and why they are important. It will be noted that the important temperature stress is a stress due to bending of the slab, and, consequently, to resist this stress the concrete must have a high resistance to bending. It must be strong in flexure.

In a manner similar to the above it could be shown that warping stresses are produced near the corner of a slab parallel to a 45° line drawn through the corner, but as a matter of fact, this corner-warping stress due to temperature is very much lower than the stress produced in a longitudinal direction at the center of the slab, as can well be understood by remembering that the overhang of the unsupported slab is less at the corner than it would be in the center of the slab.

For a complete discussion of temperature stresses in concrete road slabs, reference should be made to papers by Dr. Westergaard [8] in the proceedings of the Highway Research Board or in the booklet by R. D. Bradbury entitled, "Reinforced Concrete Pavements", published by the Wire Reinforcement Institute.[7] These warping stresses are bending stresses.

Stresses Due to Traffic Loads

Concrete in a pavement is subjected to still other stress-producing forces, the principal of which are the wheel loads of traffic. The direct vertical compressive stress produced by traffic can be instantly dismissed when it is remembered that the air pressure in even the largest and heaviest loaded truck tires rarely exceeds 100 psi and, allowing for the fact that the pressure on a road surface within the area of contact between the tire and that surface is not entirely uniform, the maximum vertical pressure on the concrete probably never exceeds 150 psi. Highway concrete as made nowadays has a compressive resistance of between 4000 and 6000 psi, and of course a bearing resistance very much higher than this. The concentrated wheel loads of traffic do, however, bend the slab wherever that wheel load is applied. One can imagine a number of different critical load positions which will produce the highest stresses in bending and among these may be mentioned:

(1) A wheel load applied at the corner of the slab at the intersection of a transverse joint with the edge,

(2) A load applied at the center of the slab, and particularly where that center rests upon a soft spot on the subgrade,

(3) Load applied along the edges of the slab, and

(4) Load applied along the edge of a transverse joint.

Generally, the bending stress produced is least when the load is applied at the center of the slab and is greatest at the corner and along the edges. Stress measurements made many years ago show that the edge stress and the corner stress are not greatly different and are the maximum stresses to be expected.

When a load bends the slab down, the motion of the slab likewise deforms the subgrade which then offers greater resistance and support. Consequently, if the subgrade were highly resistant, bending would be largely prevented and therefore only small bending stresses would be produced in the slab. The more nearly the subgrade approaches a liquid, that is, the softer it becomes, the more nearly uniform would be the distribution of pressure intensity on the subgrade due to the deflection of the slab and the less help would the slab receive from the subgrade in resisting bending stresses. So that theoretically the softer the subgrade, the higher will be the bending stress produced by traffic loads.

Actual measurements of deformation in concrete road slabs show that, to all intents and purposes, the neutral plane under bending action is near the center of the slab,—half way between the top and the bottom. Therefore, when the slab is deflected, the same amount of horizontal deformation takes place at the bottom of the slab as at the top and since the modulus of elasticity of concrete is approximately the same in tension as in compression, the resulting effect is that just about the same amount of tension is produced on one side of the slab as is the com-

pression produced on the other side. See Fig. 4. Concrete is very weak in tension with a tensile resistance of only about 1/11 to 1/12 of the compressive resistance and, even in terms of [1] modulus of rupture, the tensile resistance in bending is only 1/5 to

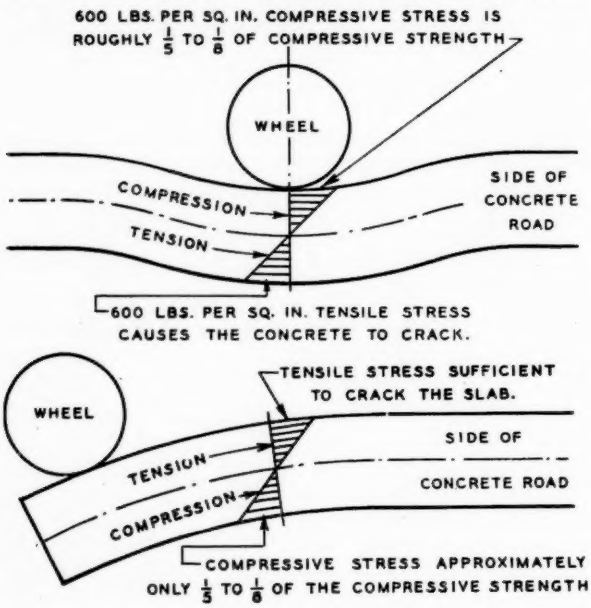

FIGURE 4. BENDING STRESSES PRODUCED IN CONCRETE ROAD SLAB.

1/8 of the compressive resistance. Accordingly, when a slab fails under traffic loads, it does not fail in compression, but it is sure to fail in tension. So again, the bending resistance of concrete for use in pavements becomes of paramount importance. For a discussion of the methods for determining stresses due to traffic loads, reference should be made to Westergaard and to Bradbury.

Repeated Loads

Concrete pavements are not like most structures which are subjected to a static load applied constantly. The fact is that a concrete pavement is always in motion and it is subjected to constantly varying stress, stress due to moisture changes to the daily cycle of temperature changes, and to the application of thousands of wheel loads. Concrete, like other materials, suffers fatigue when stress is repeated thousands of times.

Many years ago when the famous Bates Experimental Road in Illinois [9] was under investigation, repeated load tests were made on concrete beams and it was found that if concrete is subjected to thousands of load applications, it is very apt to fail at a flexural stress which is roughly 55 percent of the stress required when the load is applied only once. Accordingly, it would not be safe to design a concrete road so that the temperature and load stresses would extend up as high as the modulus of rupture, but rather should that stress be held to something under 55 percent of the modulus of rupture. Generally, the stress should not exceed one-half of the modulus of rupture. For illustration, if the modulus of rupture is found to be 700 psi it would not be safe to have the combined stresses exceed 350 psi, because failure would be bound to take place in the course of time due to fatigue and even a stress as low as 350 psi offers very little factor of safety, if any, because of the occasional overloads which a pavement is always apt to receive.

Some methods for arriving at the thickness of road slabs and notably that published by the Portland Cement Association [10] attempt to predict the amount of traffic a road is to receive and then design it to take account of the density of traffic. For illustration, if it is known that the road will carry a large number of heavy units of traffic every day so that it is stressed up to a high limit repeatedly, it is made thicker than would be the case were this same road to receive only a limited number of daily applications of the heavy units of traffic. The details of this method of design are described in detail in the P.C.A. Bulletin previously referred to.

Beam resistance as measured by the so-called modulus of rupture of concrete is seen to be the most important property concrete for pavements should

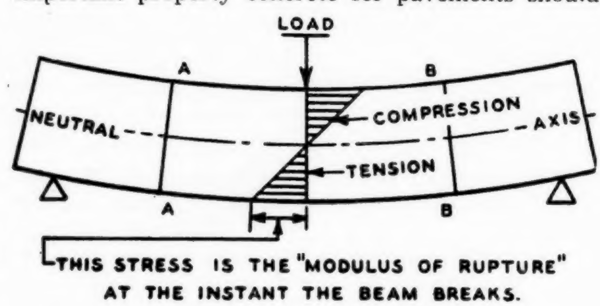

FIGURE 5. THE MEANING OF "MODULUS OF RUPTURE".

have and it therefore becomes important to thoroughly understand what is meant by the term "modulus of rupture".

Modulus of Rupture

When a beam is loaded and deflects under load (see Fig. 5), the so-called fibers suffer compression or stretching depending upon whether they are on

the compression or tension side of the neutral plane where no deformation takes place. This neutral plane, in a homogeneous mass of concrete is at the center, midway between the top and bottom of the slab and the horizontal deformations which take place above and below that plane are in accordance with a straight line. A fiber 4 inches away from the neutral plane suffers twice the deformation of one 2 inches away and, of course, the maximum deformations are equal at the top and bottom of the slab, one however being compression and the other tension, or vice versa. The stress produced is in direct proportion to the deformation and is equal to the modulus of elasticity times the unit deformation. The flexural formula for calculating the stress in a plane concrete beam under any load is as follows:

$$S = \frac{Mc}{I}$$

where

S = unit stress at either the top or the bottom of the slab or beam
M = bending moment
c = half depth of the slab
I = moment of inertia.

For a beam of square cross-section, c = the depth (d) divided by 2

$\left(\frac{d}{2}\right)$ and $I = \frac{d^4}{12}$, or

$$S = \frac{M \times 6}{d^3}$$

It is assumed that this formula, although developed for concrete loaded up only to the elastic limit also applies up to the time of rupture of the concrete, when the tensile stress exceeds the tensile resistance of the concrete and the beam breaks.

Modulus of Rupture (S) therefore is the bending stress which exists on the tension side of the beam at the time of failure.

The standard specimen for determining modulus of rupture for pavement concrete is 6 x 6 inches in cross-section and has a span of 18 inches. The load is applied at the third points. The bending moment is therefore equal to the load $\left(\frac{P}{2}\right)$ x 6 in.

$$S = \frac{Mc}{I} = \frac{P}{2} \times 6 \times \frac{6}{d^3} = \frac{18P}{d^3}$$

if d = 6 inches, as in the standard specimen,

$$S = \frac{18P}{6 \times 6 \times 6} = \frac{1}{12} P$$

The Importance of Relatively Small Differences in Modulus of Rupture

It has been shown that it is unwise to subject pavement concrete to a stress much greater than 50 percent of the modulus of rupture of the concrete because 55 percent of the modulus of rupture is really the ultimate strength under repeated loads.

Consider two concretes, A and B. A has a modulus of rupture of 600 and B of 700 psi.

$.55 \times 600 = 330$ and $.55 \times 700 = 385$ psi

Suppose repeated loads are applied which stress the concrete up to 350 psi. This stress in concrete A would be $350/600 = .58$ of the modulus of rupture and in concrete B would be $350/700 = .50$ of the modulus of rupture. Concrete A would be apt to fail under repeated loads while concrete B would be safe since A is stressed above the critical value of 55 percent of the modulus of rupture, while B is below that value. Thus, a seemingly small difference may make for rapid failure in one case and long life in another.

Influence of Aggregates on Modulus of Rupture of Concrete

Since the beam resistance as measured by modulus of rupture is such an important characteristic of pavement concrete it will be of interest to consider those characteristics of concrete and of its constituent materials which will result in a high modulus of rupture. As pointed out, the modulus of rupture is really the maximum tensile resistance of concrete as developed in bending and, consequently, anything which will affect the tensile resistance of concrete will likewise affect its modulus of rupture.

The first thought that occurs is that when tension is produced in concrete, tensile stresses exist in the mortar and also in the coarse aggregate. Likewise, bond stresses are produced which tend to destroy the adhesion between the mortar and the coarse aggregate. To obtain a high tensile resistance in the mortar it would seem necessary that as low a water-cement ratio as consistent with the proper placing of concrete be used, for this is one of the ways of increasing the tensile resistance of the mortar, and, also, it is one of the ways for increasing the adhesion of the mortar to the coarse aggregate. However, this cannot be taken as an inviolate rule; the matter is not quite as simple as that.

Further, one of the influences on adhesion is the roughness of the coarse aggregate surfaces and possibly also the shape of the coarse aggregate and the shape of the roughnesses on the surfaces of the coarse aggregate. To some extent the absorption of the coarse aggregate enters into the picture.

It is rather difficult to separate these various influences so as to show their effects quantitatively.

It has frequently been noted, however, that when extremely smooth aggregates are used, such as certain waterworn, siliceous gravels, failure of a concrete beam results, not so much due to the breaking of the coarse aggregate or failure of the mortar, but rather to the separation of the mortar from the coarse aggregate. On the other hand, when the aggregate is rough, and thereby furnishes excellent mechanical bond with the mortar, it frequently happens that the failure of the concrete reveals a number of pieces of broken coarse aggregate, even when that aggregate is very strong. The evidence seems to be, then, that roughness is a desirable property for coarse aggregate for use in concrete pavements.

It is surprising to know how much extra area is created on the surface of coarse aggregate by the

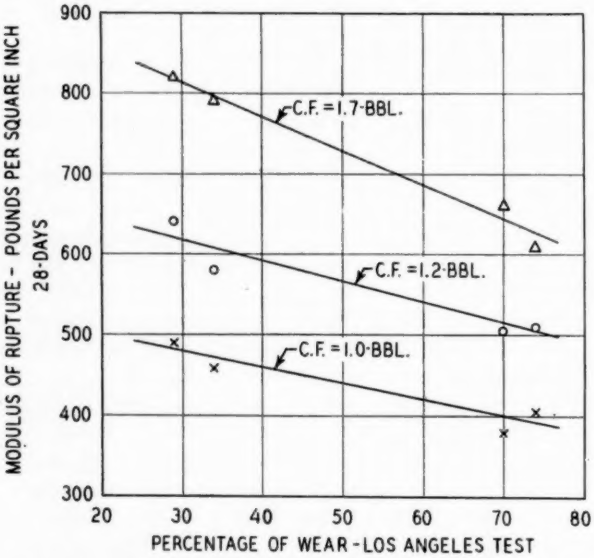

FIGURE 6. RELATION BETWEEN FLEXURAL STRENGTH OF CONCRETE AND LOS ANGELES ABRASION LOSS OF COARSE AGGREGATE. (DATA FROM TEXAS STATE HIGHWAY DEPT.)

local roughness on that surface. Such roughnesses may increase the surface area several fold over that which would prevail were the aggregate entirely smooth. Calculations made on the assumption that the surface is composed of a series of cubes and pyramids having base dimensions of 0.01 inch on a side will reveal a surprising increase in area over that of the smooth surface upon which these local roughnesses are placed. If there is more area for the mortar to adhere to, it must be obvious that there will likewise be better bond resistance. The fact is that these matters do seem to have an influence on the beam resistance of concrete.

There is still another influence, namely, the strength of the aggregate itself. The Los Angeles abrasion machine is most generally used for measuring the physical properties of coarse aggregate and it seems to be a fact that the stronger the coarse aggregate as revealed by a low percentage of wear in the Los Angeles abrasion test, the higher is the concrete beam strength.[11] See Figs. 6 and 7.

The Wear Resistance of Concrete Pavements

Since pavements are subjected to the rolling loads of rubber tires, sometimes equipped with tire chains, it becomes important to inquire as to whether this type of load application will have any serious wearing effect on the concrete and whether traffic wear will really control the life of the pavement. Experience and tests made many years ago by the Bureau of Public Roads[12] seem to show that a concrete road surface is not apt to be seriously worn by rubber tired traffic, except when the rubber tires are equipped with tire chains. However, tire chains are used primarily when the road is covered with ice or snow and except for short intervals they do not come into contact with the pavement surface.

It is true that when traffic is forced to run in a single path, such as might happen on a narrow street, with a streetcar line in the center, even a granite

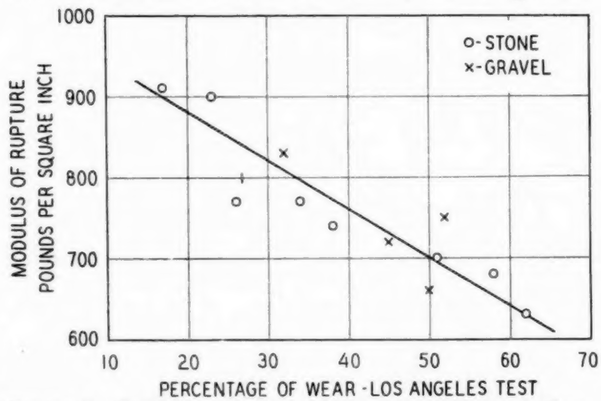

FIGURE 7. RELATION BETWEEN FLEXURAL STRENGTH OF CONCRETE AND LOS ANGELES ABRASION LOSS OF COARSE AGGREGATE. (DATA FROM GEORGIA STATE HIGHWAY DEPT.)

block pavement will show signs of considerable wear and concrete could be expected to show at least equal wear. But this is the unusual condition and general experience does not indicate that the concrete road will ever be seriously worn by traffic alone. Long before it is worn out, it will suffer the more serious effects of traffic loads which will produce excessive bending stresses.

In the Bureau of Public Roads' tests previously referred to, a number of coarse aggregates were used for the purpose of determining how soft an aggregate could be before excessive wear took place and it was shown that crushed stone in order to wear at approximately the same rate as 1 : 2 mortar would have to have a percentage of wear in the Deval Abrasion Test as high as 7.0. Nowadays, when the coarse aggregate is specified in terms of the Los Angeles Abrasion Test, there seems to be no hesitation in permitting the use of coarse aggregate having a Los Angeles abrasion loss as high as 50 percent. Apparently no excessive wear has resulted from the use of this rather soft material, although unquestionably the beam resistance has suffered.

Weather Resistance of Concrete for Pavements

A concrete pavement slab is one of the most exposed concrete structures imaginable and, furthermore, for the purpose of promoting safety, calcium and sodium salts are universally used in freezing weather. Consequently, the concrete pavement surface is subjected to a severe weathering effect and, as pointed out, this weathering effect occurs on the top surface of the concrete pavement which is weakest and least durable because of the water-gain which has taken place. The effect of these various influences, together with that of traffic has been, in too many instances, that the surface of the pavement has scaled badly and has exposed not only the underlying coarse aggregate, but also another layer of mortar which in turn is subjected to this same scaling action during succeeding years. Calcium chloride and common salt are the worst offenders in promoting scaling, when they are used in their raw state for ice removal instead of as an admixture in small amount with grit for the purpose of rendering the surface less subject to skidding accidents.

It is obvious that to produce high bending resistance in the concrete and, likewise, to produce concrete which is as durable as possible, extraordinary precautions should be used in the design of the pavement mixture to secure the qualities desired. This requires that the fine aggregate be carefully specified to produce a workable concrete with enough fines in it to prevent water-gain. Also, the ratio of fine to coarse aggregate should be of an amount which will produce sufficiently workable concrete but with a minimum of fine aggregate so that the amount of mixing water may be held to a minimum and no more mortar will appear on the surface of the slab than is necessary for proper finishing. A method for proportioning concrete which will accomplish these ends will be described a little later.[13]

There perhaps is no more important development as far as the production of durability of concrete pavements is concerned than the recent trend toward the use of some form of air-entrainment in concrete

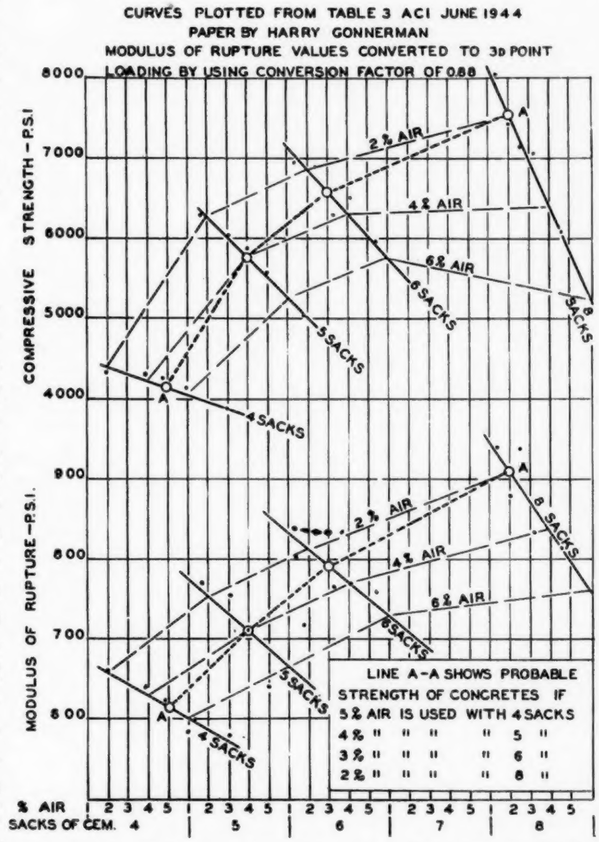

FIGURE 8. EFFECT OF AIR CONTENT ON STRENGTH WITH DIFFERENT CEMENT FACTORS.

pavement mixtures. Air-entrainment seems to be beneficial in very greatly improving the durability of concrete even when it is subjected to direct salt action. Scaling, although not perhaps entirely eliminated, is at least very greatly retarded and the life of the pavement is very materially increased by the use of air-entraining agents. Theories have been advanced as to the reasons why they do improve durability. Perhaps these theories have not been entirely proven as yet, but it is known that the desired action, that of the improvement in durability, is obtained. When an air-entraining agent is used, its effect is to somewhat reduce the strength of the

concrete and, for a given percentage of air, that strength is reduced more in a rich mix than in a lean mix so the question arises as to the proper amount of air to use in a pavement concrete where the cement factor is relatively high. In Fig. 8 is shown the effect of air on concrete containing different amounts of cement and different amounts of air.

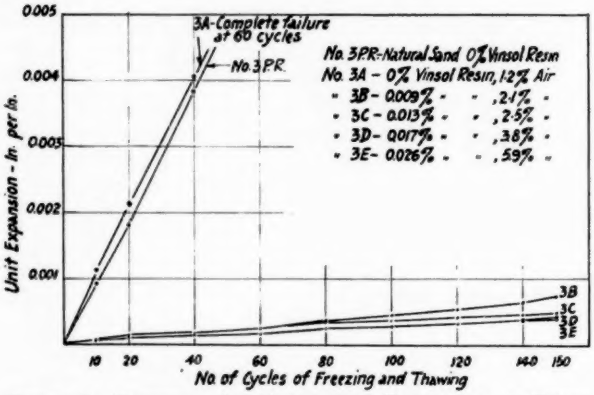

FIGURE 9. EFFECT OF AIR CONTENT ON DURABILITY OF STONE SAND CONCRETE.

It will be noted that if a high percentage of air,—say 6 percent, is used in a rich mix, there may be an actual reduction in strength as compared with that obtained with a somewhat leaner mix, 8 sacks as compared with 6 sacks. On the other hand, if the amount of air is reduced as the richness of the mix is increased, there will be an increase in strength with an increase in cement factor and this is desirable. It is questionable if as much air is needed in pavement concrete as in leaner concrete used for structures because with a somewhat richer and dryer mix, the pavement concrete is more durable in any event and in order to retain a relatively high beam strength as well as high durability, in all probability, it is desirable to accomplish this end by the use of a relatively small amount of air in the rich mix.

Tests made in our own laboratory show that the improvement in the durability of concrete by the use of as little as 2 percent of air is so marked in comparison with that containing no air that the slight amount of extra durability obtained by the use of a greater amount of air is of negligible value. Fig. 9. This is a point well worth thinking about and it will need investigation in the future.

The foregoing discussion treats of the properties desirable in concrete for pavements and it is quite evident that pavement concrete should possess the following characteristics per se, but in addition it must be so treated after placement on the subgrade that it will not develop undesirable properties which could have been avoided if handled properly.

Desirable Properties for Pavement Concrete

1. High beam strength as measured by Modulus of Rupture.

   The stresses which induce cracking are, in the main, flexural stresses produced by:

   (a) Warping from temperature and moisture differentials.

   (b) Loads of traffic.

   (c) Unequal subgrade settlement. Also, direct tension is produced by temperature and moisture contraction which is added to the tension produced by bending.

2. Relatively low thermal coefficient of expansion if possible, as this will reduce the thermal stresses.
3. Relatively low water-cement ratio which reduces shrinkage stresses, increases strength and improves durability.
4. Well graded sand with enough "fines" to help produce workability and prevent water-gain, preferably not less than 10 percent through the No. 50 sieve if feasible.

How can pavement concrete be designed to have the requisite beam strength assuming that the aggregates have been selected to conform with proper specifications? A method of proportioning which has been found to give good results is covered in reference No. 13, and need not be given here.

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(Continued on Page 22)

Some Bituminous Concrete Difficulties and Their Solutions

By LLOYD BURGESS

Engineer-Director, Bituminous Concrete Producers Association

• Bituminous concrete is established as one of our most durable and satisfactory pavement surfaces but like other types it must be properly designed and constructed for its greatest usefulness. A careful reading of the present discussion by Mr. Burgess will reveal many practical suggestions for the building of bituminous concrete pavements in the best possible manner.

WHOEVER has made a journey over Ohio's highways in recent years will remember her bituminous concrete pavements. They are everywhere and they are good.

No one has a right to be more justly proud of this accomplishment than that relatively small group of sincere and energetic individuals, which we like to refer to as the bituminous-minded men of Ohio. You will find them among the career engineers in the state and county highway departments, among the aggregate producers and bituminous material producers and, last but not least, among the plant owners and construction men. Starting under adverse conditions they planned so carefully and constructively that their product grew in quality and quantity and in favor in public and in private use.

Many Uses for Bituminous Concrete

Approximately 8,000,000 tons of plant-mixed bituminous concrete have been produced on State Highway contract construction in the last fifteen years. This has been utilized in the widening and/or resurfacing of a conservatively estimated 3500 miles of Ohio's highway system. Many more thousands of tons have been utilized by the cities and counties and by the maintenance operations of the State Highway Department.

Bituminous concrete became quite popular with the man behind the wheel. He discussed its merits favorably. You will now find throughout this state, acres of parking lots paved with plant-mixed bituminous concrete, also driveways, tennis courts and play grounds. If you happen to be passing a school ground you may see play pads of plant-mixed bituminous concrete under and around the play ground equipment, placed there to dispense with the alternating mud and dust.

Out on the R. F. D. some of the up-to-date farm flocks are now taking their meals from bituminous concrete floors. Inside and outdoor feed lots, barn floors and poultry houses are being paved for better efficiency and economy in converting high-cost feed into eggs, milk and meat.

Old Macadam an Excellent Base

During an earlier era Ohio was known for her good but rough macadam pavements. These same pavements in their old age became the best of candidates for bituminous concrete resurfacing and, because they were usually structurally sound, needed nothing to meet modern traffic demands except widening, leveling and resurfacing. All types of existing pavement have been included in Ohio's program of widening and/or resurfacing with plant-mixed bituminous concrete. The flexible or non-rigid types, however, are obviously more satisfactory as a base. The transverse joints in P. C. concrete and the longitudinal construction joints of concrete widening are sooner or later reproduced in the surface course.

Although brick surfaces are generally considered to be satisfactory as a base for bituminous concrete resurfacing, some trouble has been experienced with moisture in the cushion, accumulated through a loose brick surface, causing stripping to occur in the newly laid surface course. On certain other brick highways carrying heavy truck traffic, valleys have developed in the wheel lanes after resurfacing. This has been attributed to the displacement of the brick and/or cushion due to excessive and concentrated wheel loads.

About the year 1930, engineers in the Ohio Department of Highways began a program of salvage construction which was designed primarily to prolong the life and usefulness of the existing pavements throughout Ohio, an investment the general public had paid for the hard way and the local residents, in many instances, by abutting land assessments.

This widening and resurfacing with plant-mixed bituminous concrete, connoting efficiency and economy on the part of engineers and public officials, met with wide public approval. It provided a road, new

in all its appearances, wider and smoother than the existing, but far cheaper than new construction which did not utilize the old.

Construction Practices Have Been Greatly Improved

By 1935, Ohio owners of bituminous concrete batch plants, under the guidance of highway engineers, had modernized their plants and developed their production to the point of establishing a top record for the number of plants grouped under a high specification requirement. The construction procedure for laying, finishing and compacting the bituminous concrete required the material to be spread and finished by a self-powered finishing machine operated on steel forms or on rigid construction as planned. Compaction was to be performed with finishing rollers weighting 10 to 12 tons at a rate of from 150 to 200 sq. yds. per hour per roller. This procedure was relatively slow and a bottleneck to the potential production of the mixing plant. Excellent construction was being obtained but general dissatisfaction prevailed among contractors and producers over the respective specifications and the low total annual tonnage involved. The mixing temperature approximated 300° F. and the penetration of the asphalt used was between 50 and 60. This was Ohio's Type T-50.

About this time there arose a public demand for a greater regard for public convenience in the matter of construction detours. The bituminous industry, ever anxious to score, forthwith advanced on a lateral pass.

By using an 85 to 100 penetration asphalt an intermediate temperature mixture was produced at an approximate temperature of 250° F. This was satisfactorily laid with self-powered pavers in single lane or half width construction operations and thereafter compacted with the standard rolling equipment. Traffic was maintained through the work at all times. The whole matter proved a success and the industry went through for a touchdown. This was Ohio's Type T-35.

In this discussion of "Some Bituminous Concrete Difficulties and Their Solutions," let us first state the limitations of our intended comments. We are speaking of plant-mixed bituminous concrete produced in Ohio principally for highway use, and since time does not permit our indulgence in a discussion of all bituminous types, our remarks may be considered to apply only to the hot-mixed, hot-laid, dense-graded bituminous concrete Items T-50 and T-35.

Let us bear in mind that Item T-50 preceded T-35. It was upon the reputation of the quality of T-50 that the reputation of plant-mixed bituminous concrete salvage construction was established, and it was during this era, also, that the additional plant equipment was specified and required which raised the plant standard of efficiency to its present status.

Some of the conditions that obsoleted T-50 construction have already been stated. Only a relatively small percentage of the total tonnage produced in the last 15 years was produced under that specification. The greater tonnage was produced under Item T-35.

Let us now consider some essentials. Durability is the first requisite of a good bituminous concrete pavement. A proper regard for a few fundamental principles is all that is necessary to secure, at reasonable cost, a safe and durable bituminous concrete pavement, profitable to the public and to the producer.

Mix Design Is Important

Actually there are no great difficulties involved in the procedure of producing bituminous concrete, transporting it to the site of the work, and spreading, finishing and compacting the material, except those difficulties which arise by reason of some infraction in the procedure against well established and proven practices. We might say, therefore, that our first and chief difficulty exists in the violation of fundamentals or in taking ill advised liberties with well established practices. Its solution is to be found in a broader knowledge of, and respect for the essential principles which govern the behaviour of the specific type with which we happen to be working. For instance, the mixture composition for T-35 is designed first with a skeleton structure or framework composed of particles of coarse aggregate. When finished and compacted ready for traffic, it relies for its stability upon the stone to stone contact or semi-interlocking action of the particles of coarse aggregate.

Into the body of this compacted coarse aggregate structure, we wish to have introduced enough fines (sand) to fill the voids. Sufficient bituminous cement is next introduced to coat all areas of coarse and fine aggregate with a calculated excess of bitumen to occupy the greater percentage of the voids within the compacted fine aggregate.

Bituminous engineers of the Ohio Highway Department originated this design, and hundreds of miles of excellent construction bear witness of its

value as a pavement. It has, however, its own peculiar characteristics and its limitation of variation.

Now, if we may repeat ourselves, consider a bituminous concrete three-inch mat spread and thorougly compacted. In order that the pavement be impervious to surface water and at the same time provide good traction to vehicular traffic, it is incumbent on the engineer to design the mix in such proportions of fine and coarse aggregates and bituminous cement, that the aggregates, while compacting, can be forced by the kneading action of the roller into such relative position that the fine aggregate will occupy the voids of the coarse aggregate, and the bitumen will provide a surface film over all areas with sufficient excess to occupy the greater portion of the minute voids within the granular material.

If it were not for the presence of the bituminous cement in this compacted mat, it would be permeable. If the aggregates were coated with bitumen without excess, the unfilled minute voids would still provide a medium of permeability. As we approach the minimum of bituminous content in the mix, which is necessary to obviate permeability, we have also in mind the fact that the usable maximum for this purpose could and probably would defeat our cause in keeping the bitumen in control sufficiently to avoid the creation of a slippery surface condition.

To develop the safest surface, we desire that the coarse aggregate be prominent in the surface area of the pavement. One of the difficulties experienced in bituminous construction is a determination on the part of some to indulge in extremes in controlling the one condition or the opposite. For instance, the novice who champions the cause against slippery pavements will invariably minimize the relative importance of the bitumen content of the mix. He knows but one remedy for a fatty condition, and that is to reduce the asphalt. There are other contributing factors which he should recognize, such as improper conditioning of the aggregate (foaming), segregation of the aggregates, introduction of traffic on fresh hot pavements, etc. When this reduction of bituminous content is carried to the point where the infiltration of water is followed by stripping, raveling, or frost damage, he is completely nonplused. Another individual who is determined to fill a pavement so full of bitumen that it will be completely impervious to moisture, longer lived, and without tendency to ravel, will likewise be chagrined when his extreme methods are rewarded with glassy surfaces or chronic extrusion.

Since these two very important factors are usually approached from opposite extremes it is apparent that the authority for control should be vested only in those who have due respect for each of the beforementioned conditions. Without this knowledge and the appreciation of its critical limitation of variation, mix design and control can easily develop into a hazardous trend in either direction.

The chief characteristic of this flexible type, when properly designed as to mix composition and depth of construction, is inherent stability. Though stable within its own depth, it cannot be constructed upon any kind or condition of substructure without regard for the essential stability of the existing pavement, base or prepared subgrade upon which the new bituminous construction is to be placed.

Herein lies another difficulty. Since we sometimes speak of the dense graded bituminous concrete surface course as being a flexible but stable mat, some have erroneously inferred that it possesses some quaint and peculiar quality of elasticity by virtue of which the type can be subjected successfully to all manner of adverse conditions. It cannot.

Solution? Plan the whole way: subgrade correction, side drainage, and base failure replacement. If all new construction is required, provide a stable flexible sub-base on a well compacted subgrade.

Since quality is the chief attribute of a durable product it necessarily follows that the component parts must likewise meet a specified standard of quality. In the processing of bituminous concrete it should be borne in mind that the quality of the end product, that is the pavement in place, finished and compacted, will reflect the quality of the component parts. The service record of many miles of bituminous concrete has proven that best pavements are those which have been constructed of materials of standardized quality.

There is a continual agitation, however, toward experimentation dictated almost universally by the desire to utilize an inferior material in the vague and somewhat foggy conviction that the end product will be just as good. Such experimentation quite often leads us around in a complete circle. In the name of economy we resort to a cheaper aggregate which does not do so well. We then compensate its behavior by increasing the proportion of fine aggregate, on the theory that the coarse aggregate will be protected from the load impact and traffic abrasion by suspending the coarse particles in matrix. When this mix lacks stability we lower the penetration of the asphalt. When this mix develops char-

acteristic but indecent behavior we resort, after much deliberation, to better coarse aggregate and we reduce the proportion of fine to coarse aggregate. After much consultation, it becomes apparent that the penetration of the asphalt is too low and we go back to the original penetration, to an aggregate of known standard of quality and to an end product quite as satisfactory as the one from which we deliberately deleted quality.

By the time the public has paid for this round of experimentation new personnel may have assembled itself and is anxious to get started on the same or a similar merry-go-round.

Essentials for Durability

Durability, we have said, is the first attribute of a good pavement. To secure durability we have designed stability and non-permeability into the mix-type and have recommended quality in the component parts. If these factors are to be accomplished in the finished pavement it will be necessary for some persons in charge at the plant and at the street to believe in them and to care.

Next, let us consider compaction and the characteristic kneading action of the roller, hereinbefore mentioned. There has never been any other method devised for compaction of bituminous concrete that will develop the density and stability within the course, like the kneading action of a slow moving asphalt roller. Anything that gives the material precompaction before the roller is introduced is not necessarily an aid, but may perhaps be a hindrance to the roller in its effort to develop the kneading action within the material. Restriction of the kneading action results in the restriction of the distribution of the coarse and fine aggregates into their proper relative positions and in the development of density so absolutely necessary, first, for the exclusion of surface water; second, for the retention of free asphalt within the minute voids of the granular material; third, for the development of the stability necessary to support vehicular traffic without displacement.

What has happened to our faith in the past practices of rolling? No equipment is so definitely adapted to its work in bituminous construction as the asphalt roller is adapted to compaction. We *must* have density developed in the bituminous concrete at the *time of construction*.

For some time there has been a growing conviction among technicians that our roller specifications are in a measure obsolete. They apparently are of the opinion that the present requirements of tons or square yards per hour per roller, when enforced, result in compaction-plus. This undoubtedly is true since, of necessity, the requirement contains some factor of safety. Losing sight of the fact that past practice has secured the density necessary for durability, they would abandon the specification control while pursuing the idea of evolving a field test to determine the density of the pavement as it develops during compaction. This test would indicate the minimum of rolling necessary to secure the minimum density.

No such test has been developed which is definite and practical. This matter has become almost a frustration with some and in the meanwhile, undercompaction has flourished. Not to the extent that failures abound, but to a degree which has caused grave concern to the thoughtful who sense an attitude of indifference and a trend toward laxity. The roller production did not increase proportionately with the up swing in hourly plant production. Some engineers and contractors attempted to rationalize this departure by advancing the opinion that after all, vehicular traffic is the chief agent of compaction.

The trend was finally given pause by the fact that some late fall construction went into the winter undercompacted. Prevailing low atmospheric temperatures did not permit traffic to develop the minimum density necessary for the exclusion of surface water. Frost damage and traffic abrasion thereafter occurred sufficiently to prove the fallacy of the procedure.

We are ever restless and desirous of change. Not all change is progress. Some variations make things different but not essentially better. Careful or sometimes bold departures from past practices are necessary for advancement but we hold that it is better to be entrenched behind a record of good construction than to be perched precariously a step and a half ahead of progress.

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National Crushed Stone Association
January 27, 28, 29, 1947

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Agricultural Limestone Division
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Board of Agricultural Limestone Division Holds Midyear Meeting

UNDER the Chairmanship of S. P. Moore, a number of items of real importance to members of the Agricultural Limestone Division were discussed and acted upon by the Board of Directors at its midyear meeting on July 19, 1946, at the Hotel New Yorker, in New York City.

One of the most important actions was the unanimous adoption of a Statement of Policy which is reproduced on page 20 of this Journal. This policy was drafted and presented by a committee composed of Chairman P. E. Heim, Otho M. Graves, James Eells and Horace C. Krause. It clearly sets forth the future course of action that will be followed by the Division and should serve as a guide to all members.

In line with the decision of the Executive Committee at its meeting held in May, copy of a statement, since filed by the Division, protesting the rail carriers' request for a rate increase of 20 cents per ton, was read, discussed and approved.

Managing Director Henry A. Huschke reported on the first year's activities of the Division. He stated that member companies had purchased 117,000 of the invisible ink post cards and 193,000 copies of the folder, "Repair and Rebuild with Limestone and Legumes". In addition over 11,000 copies of the folder were given to public agencies for free distribution.

He also stated that the series of five newspaper advertisements for use by member companies and banks had been prepared and were available for use by interested parties. Excerpts of letters from a number of banks were presented to show that they were highly appreciative of this service.

J. R. Boyd, Secretary-Treasurer of the Division, reported on recent legislative matters which directly or indirectly would affect the industry. He also reported on the fiscal affairs of the Division, pointing out that during the first six months expenditures had been kept within the approved budget. He stated, however, that if the program of activities is to be maintained at an effective level during 1947 means of increasing revenue would have to be found. It was the opinion of the Board that it should be possible to obtain enough new members to solve this problem.

A sombre note was injected into the meeting when a letter was read from E. J. Krause announcing his resignation from the Executive Committee and Board of Directors. After the Board accepted his resignation with deepest regret Mr. Krause was elected the first Honorary Director, and his son, Horace C. Krause, was elected to fill the vacancy on the Board and on the Executive Committee, created by his father's resignation.

The following Directors were in attendance:

Chairman
S. P. Moore, Cedar Rapids, Iowa

Northeast Region
H. E. Battin, Jr., South Bethlehem, N. Y.

East Central Region
S. B. Downing, Jr., Lexington, Ky.
A. B. Rodes, Nashville, Tenn.
O. M. Stull, Buchanan, Va.

North Central Region
H. A. Clark, Chicago, Ill.
James Eells, Cleveland, Ohio
E. E. Haapala, Zumbrota, Minn.
W. R. Sanborn (representing A. E. Hanshaw) Kankakee, Ill.
A. K. Hausmann, Cleveland, Ohio
P. E. Heim, Youngstown, Ohio
W. E. Hewitt, East St. Louis, Ill.
H. C. Krause, St. Louis, Mo.
F. W. Mumma, St. Louis, Mo.
R. M. Seifried, Findlay, Ohio

Southern Region
W. M. Palmer, Ocala, Fla.
E. V. Scott, Dallas, Texas
C. M. Sims, Gaffney, S. C.

Representing the National Crushed Stone Association
Otho M. Graves, Easton, Pa.

Others Present:

Staff
J. R. Boyd, Washington, D. C.
Henry A. Huschke, Washington, D. C.

Guests
Wm. M. Andrews, New Castle, Pa.
G. A. Austin, Decatur, Ga.
Harry Brandon, Melvin, Ohio
Rede Larson, Stewartville, Minn.
M. E. McLean, East St. Louis, Ill.
S. A. Phillips, Chicago, Ill.
Russell Rarey, Columbus, Ohio
N. C. Rockwood, Chicago, Ill.
F. W. Schmidt, Jr., Morristown, N. J.
J. B. Terbell, New York, N. Y.

AGRICULTURAL LIMESTONE DIVISION

NATIONAL CRUSHED STONE ASSOCIATION

STATEMENT OF POLICY

ADOPTED JULY 19, 1946

IT IS the inevitable result of farming in the humid areas of this nation that there is dissolved and leached out of the soil certain chemical elements that are essential to the economical production of wholesome and nutritious food and feed crops. This directly affects the health and welfare of the nation.

The mineral elements which suffer the greatest losses from the dissolving and leaching action of rain water, an action over which man has little or no control, are the basic or alkaline elements, notably calcium and magnesium, the chief components of limestone and dolomite.

The effect of these losses is an unbalanced soil, a soil that does not produce at an economical rate and whose crops are lacking in the needed amounts of minerals to maintain the people and animals of this nation in a reasonably good state of health. This fact is well exemplified by the large number of young men who were unacceptable for military service due to health defects, the figure running as high as 70 per cent rejections in areas where the mineral content of the soil is very low.

Technicians who are best informed on this subject, namely, the agronomists and soil chemists of our state colleges and experiment stations, have determined that over 50 million tons of agricultural limestone are required annually to replace the yearly loss of calcium and magnesium and to keep our soils in a reasonably productive state. Our present rate of consumption is less than half that amount.

From the standpoint of monetary investment it is highly profitable to apply agricultural limestone to the soil. However, a considerable period of time is required before the full return is realized. This fact makes the investment not too attractive even to many farmers who have the money available.

The problem of replacing the lost calcium and magnesium further is aggravated by the fact that about 40 per cent of the farms in the United States are operated by tenants who, for the most part, do not have the interest in the future productivity of the land that an owner has and, therefore, do not invest in limestone.

Great strides have been made since 1936 through the programs of the Agricultural Adjustment Agency (now the Field Service Branch of the Production and Marketing Administration) toward solving the problem of getting back into our soils the calcium and magnesium that have been lost through cropping and leaching. But the task is only half done. It is to the interest of the entire citizenry of this nation that these efforts be continued and expanded.

Obviously, to attain the goal of 50 million tons per year is no small job. It is one that will require for an indeterminate number of years, the complete cooperation of government and industry. The fullest efforts of both are required to make farmers mindful of the necessity of more than doubling their soil-liming activities. This cannot be done without the activating influence of the Conservation Materials Program of the Field Service Branch. Nor can it be done unless the farmers of this nation are convinced that their own walfare, as well as that of the nation, is at stake.

Therefore, in the light of the foregoing, it is the declared policy of the Agricultural Limestone Division of the National Crushed Stone Association, THAT:

1. In the interest of the national welfare and the conservation of our soils, the Agricultural Limestone Division will actively and vigorously support a continuance of Federal aid to finance government programs designed to restore to an optimum level the calcium and magnesium content of our soils.

2. The Agricultural Limestone Division will continue, to an even greater extent, to assist in securing for the farmer and the nation as a whole, a well balanced soil conservation program. To this end the Division proposes to consult, from time to time as may be appropriate and feasible, with the Federal, State and local agencies concerned.

3. Federal aid will be supported until this industry through its own augmented efforts in merchandizing, promoting and financing, is able to sell through the usual commercial channels the tonnage of agricultural limestone recommended by our well informed agronomists and soil chemists.

For the foregoing purposes the Division will work energetically and wholeheartedly.

PRA Announces Progress on Interstate Highway System

THIRTY-NINE States and the District of Columbia have accepted without reservation the integration by the Public Roads Administration of routes proposed by the States to form the national interstate highway system, Commissioner Thomas H. MacDonald announced.

Of the nine remaining States, four desire alteration of the integrated system proposed. Two of these States accepted a portion of the routes included in the tentative integration but rejected certain sections without alternative proposal. Another State followed the same course except that additional mileage was proposed. One State accepted the proposed system in entirety but requested inclusion of additional routes.

Five States have not as yet responded to Public Roads' recommendations, but the prospect of early agreement with most of the nine States "is not discouraging", Commissioner MacDonald said.

Development of a 40,000-mile interstate highway system was authorized by the Federal-Aid Highway Act of 1944, and the States were asked last year to recommend routes for inclusion in the system. The total length of routes selected by State highway departments was 45,074 miles, which included some duplicate mileage and more than 2,000 miles of circumferential and distributing routes in urban areas.

After reviewing the initial route selections recommended by the States, which in some instances involved disagreement between adjoining States concerning connections at State boundaries or the proposal of alternate routes within a State, Public Roads offered a tentative integration of the system.

All circumferential and distributing routes in urban areas were omitted from the tentative integration presented for State consideration. The main routes between and across cities which are included in the interstate system as recommended by Public Roads include 37,170 miles. This leaves a balance of 2,830 miles within the 40,000-mile statutory limitation, which is considered a sufficient reserve for the later selection of circumferential and distribution routes, Commissioner MacDonald said.

The Federal-Aid Highway Act of 1944 did not authorize a specific appropriation for the development of an interstate highway system, but provided for an annual appropriation of $225,000,000 in each of three fiscal years for improvements on the Federal-Aid system and $125,000,000 for highway projects on the system in urban areas. Since the interstate system will automatically become a part of the Federal-Aid system these funds will be available for expenditure on the system.

Development of the system eventually will provide two-lane, four-lane and in some instances six-lane highways for fast-moving traffic between all cities having a population of 100,000 or more and a majority of the cities of 10,000 to 100,000 population.

Minnesota Agricultural Limestone Producers Discuss Problems at Rochester

APPROXIMATELY twenty-five members of the Minnesota Agricultural Limestone Producers Association and representatives of the State and County AAA offices met during the evening of August 2, 1946, at Rochester, Minnesota, to discuss their mutual problems with reference to the limestone program for the balance of this year.

Ralph Childs, who is in charge of purchasing and distributing conservation materials in the state, was introduced by "Red" Bryan, President of the Association. Mr. Childs asked the producers for their full cooperation to the end that all orders for limestone be delivered prior to the end of the year. He stressed the fact that undelivered material helps no one and makes disgruntled farmers.

The problem, however, appears to be a dual one. In some areas of the State there are producers who have no more orders to fill. To them it is a question of finding additional business to keep their plants running.

Suggestions were made by various individuals, including Messrs. Ralph Childs and Henry A. Huschke, as to selling methods that have proved successful in the past. Members of the Minnesota Agricultural Limestone Association decided to hold another meeting in the near future to give further consideration to ways and means of gaining their objectives.

In addition to the guests the following producers were present: "Red" Bryan, W. L. Bryan, Martin Bustad, E. E. Haapala, Edwin Kappers, Rede Larson, Einar Nielsen, Clarence Paulson, Perry Pederson, and Walter Stussy and his son.

REFERENCES

(Continued from Page 14)

8 "Analysis of Stresses in Concrete Pavements Due to Variation in Temperature," by H. M. Westergaard, Proceedings Sixth Annual Meeting of Highway Research Board, Washington, D. C., 1926.

9 "Bates' Experiment Road" Bulletin 18, Illinois Department of Public Works.

10 "Concrete Road Design, Simplified and Correlated with Traffic," by Frank T. Sheets, Portland Cement Association, Chicago, Ill.

11 "The Relation Between Los Angeles Abrasion Test Results and the Service Records of Coarse Aggregate", by D. O. Woolf, July-August 1938 Crushed Stone Journal. Also, in Seventeenth Proceedings of Highway Research Board, 1937.

12 "Accelerated Wear Tests of Concrete Pavements" by F. H. Jackson and J. T. Pauls, A. S. T. M. Proceedings, Vol. 24, Part II.

13 "How to Proportion Concrete for Pavements," by A. T. Goldbeck and J. E. Gray, in "Stone Briefs," No. 2, National Crushed Stone Association, Washington, D. C. Also in "The Proportioning of Concrete," by A. T. Goldbeck, National Crushed Stone Association, Published by National Ready Mixed Concrete Association, Washington, D. C.

Federal-Aid Highway Commitments Not Affected by Curtailment Order

CURTAILMENT of Federal construction contracts ordered by Reconversion Director John R. Steelman, effective August 6, apparently does not apply to Federal-aid highway grants where the Federal Government has already made commitments to the States through the approval of programs by the Public Roads Administration. This advice has been transmitted to the State Highway Departments by Commissioner MacDonald after discussion with the Office of War Mobilization and Reconversion. At the same time Mr. MacDonald urged the State Highway Departments to keep Federal-aid highway expenditures at a minimum consistent with President Truman's policy in curtailing the Federal works program for the fiscal year 1947.

The Steelman Order (Directive 128) instructed all Federal agencies to stop awarding construction contracts, with certain exceptions, from August 6 until October 1, 1946. During the period covered no contract for new construction can be awarded without the express permission of the Office of War Mobilization and Reconversion. The construction of access roads to timber lands was among the few exemptions from the order. The purpose of the order is to trim the proposed $1,600,000,000 public works program by approximately $700 million to conform to the President's anti-inflation budget.

In view of the fact that the present highway program is progressing far below normal expectations, it is believed in some quarters that the Steelman "freeze" order will not seriously curtail the current program. As of June 30, 1946, approved programs not completed aggregated $595 million of which $325 million represent grants from the Federal Government. Authorized programs on which no work is underway accounted for $257 million of this total, involving Federal participation in the amount of $126 million. None of these amounts is subject to obligatory curtailment under the Steelman order. These approved programs would permit continuance of construction for from six to eight months at present levels. Furthermore, the Steelman "freeze" order does not affect planning of highway projects.

Mr. MacDonald in his letter to the State Highway Departments requested continuation and even more rigid application of the policy of rejecting bids where prices were excessive. Projects requiring structural steel should be wholly eliminated until conditions change radically so that fabricators will be able to obtain definite commitments as to delivery and firm prices from the steel mills.

Secondary Roads in Postwar Plan

MECHANIZATION of the farm has made the local or county road a major consideration in our highway construction program, declared James J. Skelly, president of the American Road Builders' Association in a recent address. With an estimated 98 per cent of our farm crops moving to market by truck, it is absolutely necessary that we improve and extend our secondary roads, he asserted.

"Agriculture has turned to motor transportation during the war years to an extent not generally realized," said Mr. Skelly. "More than one-third of all trucks in the United States are used on the farms. They haul milk, live stock, poultry, eggs, fruit, vegetables, grains and other farm products to market. It is vital to the life and health of our urban communities that good roads be provided to keep the lines of supply open all the time. Yet only 49 per cent of the nation's 1,928,000 miles of local and county roads have all-weather surfaces.

"Need for extending and improving our farm-to-market system was recognized by Congress in the Federal-Aid Highway Act of 1944 which apportioned 30 per cent of the billion-dollar-a-year construction fund for this purpose as against 45 per cent for state highways and 25 per cent for urban thoroughfares," Mr. Skelly pointed out.

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